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Agricultural Memorandum No 839

# The evaporation of intercepted water.

by N. Thompson

1. Introduction. The rate of transfer of water vapour from a canopy is given by the combination formula

$$\lambda E = \frac{\Delta'(R_N - G) + \varrho c_p \delta q / r_a}{\Delta' + c_p (1 + r_s / r_a)/\lambda} \qquad (1)$$

A canopy wetted by rain has negligible bulk stomatal resistance and the ratio of evaporation/transpiration rates for wet and dry canopies is written usually as

$$\frac{(\lambda E)_{wet}}{(\lambda E)_{dry}} = \frac{\Delta' + c_p (1 + r_s / r_a)/\lambda}{\Delta' + c_p/\lambda} \qquad (2)$$

This ratio is greater than 1 and so the wetted canopy is cooler than a dry one. As a consequence the density stratification of the atmosphere above the wet canopy is less unstable (or more stable) and the aerodynamic resistance $r_a$ is larger. Equation (2) is incorrect therefore. The errors involved in using this equation are explored in the remainder of the Memorandum.

2. Theory. The required theory has been given by Thompson (1978). This allows the calculation of water vapour fluxes from the canopy for various values of $r_s$ using Eq.(1) and hence the ratio of evaporation (or transpiration) rates from wet and dry canopies. The usual approximation to this ratio (Eq.(2)) is determined using the same theory.

3. Results and discussion. Calculations were carried out for the following ranges of variables:

| | |
|---|---|
| $R_N - G$ | 0 to 500 $wm^{-2}$ |
| $\delta q$(screen) | 0.001 to 0.008 |
| T(screen) | 5 to 25 deg C |
| u(10) | 2, 10 $ms^{-1}$ |
| $r_s$ | 0 to 100 $sm^{-1}$ |
| $z_o$ | 0.01, 0.1 m |

The calculations broke down in some cases with zero available energy and light winds: here the downward flux of sensible heat needed to balance the upward flux of latent heat was associated with a strong temperature inversion, and the levels of turbulence were too low for the application of the usual relations for the diabatic profiles of wind, temperature and humidity. Latent heat fluxes are of course very small in these conditions.

The results are summarised in Table 1. $r_s$ = 20 $sm^{-1}$ corresponds to a dense canopy (leaf area index > ~ 6), freely supplied with water and with stomata fully open. Somewhat larger values may occur when high evaporative demand causes partial closure of the stomata. $r_s$ = 100 $sm^{-1}$ would be appropriate to a sparse canopy (LAI~1), and $r_s$ = 40 $sm^{-1}$ to a canopy with moderate leaf development, in each case without water stress and with stomata fully open.

It is seen that some overestimation of the ratio is associated with the use of Eq(2) but usually by only 1 or 2 percent, unless the evaporative demand is large and the surface is rough, when errors may increase to some tens of percent. It is perhaps of interest to note the wide range of values of the ratio which can occur for crops with different surface roughness, different leaf area indices and at different wind speeds.

Any comments or suggestions on this paper should be referred to the author.

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Reference

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| $z_o$ (m) | T (deg C) | $R_N - G$ ($Wm^{-2}$) | $\delta q$ = 0.001 | | | | $\delta q$ = 0.002 | | | | $\delta q$ = 0.005 | | | | $\delta q$ = 0.008 | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | u = 2 $ms^{-1}$ | | u = 10 | | u = 2 | | u = 10 | | u = 2 | | u = 10 | | u = 2 | | u = 10 | |
| | | | R(1) | R(2) | R(1) | R(2) | R(1) | R(2) | R(1) | R(2) | R(1) | R(2) | R(1) | R(2) | R(1) | R(2) | R(1) | R(2) |
| 0.01 | 5 | 0 | - | - | 1.36 | 1.36 | - | - | 1.36 | 1.36 | - | - | 1.33 | 1.33 | | | | |
| | | 100 | 1.10 | 1.11 | 1.35 | 1.38 | 1.09 | 1.10 | 1.36 | 1.36 | 1.04 | 1.08 | 1.25 | 1.36 | | | | |
| | | 200 | 1.12 | 1.12 | 1.38 | 1.39 | 1.11 | 1.12 | 1.37 | 1.39 | 1.09 | 1.11 | 1.31 | 1.36 | | | | |
| | | 500 | 1.15 | 1.15 | 1.40 | 1.41 | 1.14 | 1.15 | 1.39 | 1.40 | 1.13 | 1.14 | 1.35 | 1.39 | | | | |
| | 15 | 0 | - | - | 1.26 | 1.26 | - | - | 1.26 | 1.26 | - | - | 1.25 | 1.25 | - | - | 1.18 | 1.24 |
| | | 100 | 1.07 | 1.08 | 1.26 | 1.28 | 1.07 | 1.07 | 1.26 | 1.26 | 1.03 | 1.06 | 1.22 | 1.26 | 1.00 | 1.04 | 1.20 | 1.25 |
| | | 200 | 1.08 | 1.09 | 1.28 | 1.28 | 1.08 | 1.08 | 1.27 | 1.28 | 1.06 | 1.08 | 1.26 | 1.26 | 1.04 | 1.07 | 1.18 | 1.26 |
| | | 500 | 1.10 | 1.10 | 1.29 | 1.29 | 1.10 | 1.10 | 1.29 | 1.29 | 1.09 | 1.10 | 1.27 | 1.28 | 1.08 | 1.09 | 1.24 | 1.28 |
| | 25 | 0 | - | - | 1.18 | 1.18 | - | - | 1.18 | 1.18 | - | - | 1.12 | 1.18 | - | - | 1.12 | 1.17 |
| | | 100 | 1.05 | 1.05 | 1.19 | 1.19 | 1.05 | 1.05 | 1.18 | 1.18 | 1.03 | 1.04 | 1.18 | 1.18 | 1.01 | 1.03 | 1.17 | 1.17 |
| | | 200 | 1.06 | 1.06 | 1.19 | 1.19 | 1.05 | 1.06 | 1.19 | 1.19 | 1.05 | 1.05 | 1.18 | 1.18 | 1.03 | 1.05 | 1.15 | 1.18 |
| | | 500 | 1.07 | 1.07 | 1.20 | 1.20 | 1.07 | 1.07 | 1.19 | 1.20 | 1.06 | 1.07 | 1.19 | 1.19 | 1.06 | 1.06 | 1.17 | 1.19 |
| 0.1 | 5 | 0 | - | - | 2.04 | 2.04 | - | - | 2.04 | 2.04 | - | - | 1.81 | 1.99 | | | | |
| | | 100 | 1.24 | 1.27 | 2.03 | 2.08 | 1.11 | 1.24 | 2.04 | 2.04 | .98 | 1.10 | 1.86 | 2.04 | | | | |
| | | 200 | 1.29 | 1.31 | 2.03 | 2.10 | 1.24 | 1.29 | 2.02 | 2.08 | 1.04 | 1.21 | 1.87 | 2.04 | | | | |
| | | 500 | 1.37 | 1.39 | 2.11 | 2.13 | 1.34 | 1.37 | 2.03 | 2.12 | 1.25 | 1.34 | 1.95 | 2.09 | | | | |
| | 15 | 0 | - | - | 1.75 | 1.75 | - | - | 1.75 | 1.75 | - | - | 1.59 | 1.75 | - | - | 1.53 | 1.69 |
| | | 100 | 1.17 | 1.19 | 1.74 | 1.79 | 1.10 | 1.17 | 1.75 | 1.75 | .99 | 1.08 | 1.61 | 1.75 | 1.00 | 1.04 | 1.57 | 1.72 |
| | | 200 | 1.21 | 1.22 | 1.75 | 1.80 | 1.18 | 1.21 | 1.74 | 1.79 | 1.03 | 1.16 | 1.69 | 1.75 | 0.98 | 1.10 | 1.58 | 1.72 |
| | | 500 | 1.26 | 1.27 | 1.81 | 1.82 | 1.24 | 1.26 | 1.76 | 1.81 | 1.19 | 1.24 | 1.69 | 1.79 | 1.14 | 1.21 | 1.63 | 1.75 |
| | 25 | 0 | - | - | 1.52 | 1.52 | - | - | 1.52 | 1.52 | - | - | 1.45 | 1.52 | - | - | 1.42 | 1.50 |
| | | 100 | 1.12 | 1.13 | 1.51 | 1.54 | 1.09 | 1.12 | 1.52 | 1.52 | .99 | 1.06 | 1.46 | 1.52 | 0.98 | 1.03 | 1.43 | 1.50 |
| | | 200 | 1.14 | 1.15 | 1.52 | 1.55 | 1.12 | 1.14 | 1.51 | 1.54 | 1.04 | 1.11 | 1.52 | 1.52 | 1.00 | 1.07 | 1.41 | 1.52 |
| | | 500 | 1.17 | 1.17 | 1.55 | 1.56 | 1.16 | 1.17 | 1.54 | 1.56 | 1.13 | 1.16 | 1.51 | 1.55 | 1.09 | 1.14 | 1.47 | 1.52 |

Notes: (a) R(1) is calculated using Eq(1); R(2) represents the approximation given by Eq(2).

(b) In stable conditions (corresponding usually to stronger winds with larger humidity deficits) errors up to about 3% may occur in the listed ratio, caused by the successive approximation routine used in stable conditions.

| | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 0 | - | - | 1.72 | 1.72 | - | - | 1.61 | 1.69 | - | - | 2.80 | 2.80 | - | - | 2.54 | 2.80 |
| | 5 | 100 | 1.21 | 1.22 | 1.73 | 1.77 | 1.08 | 1.18 | 1.59 | 1.72 | 1.54 | 1.57 | 2.85 | 2.93 | 1.29 | 1.50 | 2.58 | 2.80 |
| | | 200 | 1.25 | 1.25 | 1.77 | 1.78 | 1.18 | 1.23 | 1.66 | 1.72 | 1.63 | 1.65 | 2.94 | 2.98 | 1.50 | 1.60 | 2.69 | 2.94 |
| | | 500 | 1.30 | 1.31 | 1.81 | 1.82 | 1.27 | 1.29 | 1.73 | 1.80 | 1.78 | 1.79 | 3.05 | 3.07 | 1.71 | 1.77 | 2.90 | 3.05 |
| | | 0 | - | - | 1.52 | 1.52 | - | - | 1.40 | 1.47 | - | - | 2.31 | 2.31 | - | - | 2.03 | 2.24 |
| 0.01 | 15 | 100 | 1.15 | 1.15 | 1.53 | 1.55 | 1.00 | 1.09 | 1.44 | 1.50 | 1.38 | 1.40 | 2.36 | 2.39 | 1.05 | 1.30 | 2.13 | 2.31 |
| | | 200 | 1.17 | 1.17 | 1.56 | 1.57 | 1.09 | 1.15 | 1.42 | 1.52 | 1.44 | 1.45 | 2.41 | 2.43 | 1.28 | 1.40 | 2.13 | 2.37 |
| | | 500 | 1.21 | 1.21 | 1.58 | 1.59 | 1.17 | 1.20 | 1.50 | 1.57 | 1.55 | 1.55 | 2.48 | 2.49 | 1.46 | 1.52 | 2.32 | 2.46 |
| | | 0 | - | - | 1.36 | 1.36 | - | - | 1.28 | 1.34 | - | - | 1.90 | 1.90 | - | - | 1.72 | 1.90 |
| | 15 | 100 | 1.10 | 1.10 | 1.37 | 1.38 | 1.02 | 1.07 | 1.31 | 1.36 | 1.26 | 1.27 | 1.95 | 1.96 | 1.07 | 1.21 | 1.83 | 1.90 |
| | | 200 | 1.11 | 1.12 | 1.38 | 1.38 | 1.07 | 1.10 | 1.32 | 1.36 | 1.29 | 1.30 | 1.97 | 1.98 | 1.21 | 1.27 | 1.83 | 1.95 |
| | | 500 | 1.14 | 1.14 | 1.40 | 1.40 | 1.12 | 1.13 | 1.35 | 1.39 | 1.36 | 1.36 | 2.01 | 2.02 | 1.31 | 1.35 | 1.92 | 2.00 |
| | | 0 | - | - | 3.09 | 3.09 | - | - | 2.67 | 3.08 | - | - | 6.21 | 6.21 | - | - | 5.37 | 6.21 |
| | 5 | 100 | 1.49 | 1.56 | 3.07 | 3.18 | 0.98 | 1.24 | 2.81 | 3.09 | 2.31 | 2.47 | 6.24 | 6.49 | 1.07 | 2.15 | 5.67 | 6.21 |
| | | 200 | 1.60 | 1.64 | 3.10 | 3.21 | 1.15 | 1.51 | 2.83 | 3.09 | 2.57 | 2.68 | 6.30 | 6.56 | 1.70 | 2.51 | 5.68 | 6.49 |
| | | 500 | 1.76 | 1.80 | 3.24 | 3.28 | 1.55 | 1.72 | 2.95 | 3.23 | 2.99 | 3.07 | 6.63 | 6.73 | 2.56 | 2.97 | 6.02 | 6.67 |
| | | 0 | - | - | 2.51 | 2.51 | - | - | 2.11 | 2.44 | - | - | 4.78 | 4.78 | - | - | 3.93 | 4.77 |
| 0.1 | 15 | 100 | 1.36 | 1.40 | 2.51 | 2.58 | 0.99 | 1.19 | 2.19 | 2.51 | 1.96 | 2.04 | 4.81 | 4.98 | 0.96 | 1.40 | 4.17 | 4.77 |
| | | 200 | 1.43 | 1.45 | 2.53 | 2.60 | 1.13 | 1.37 | 2.21 | 2.51 | 2.13 | 2.19 | 4.87 | 5.03 | 1.19 | 1.97 | 4.20 | 4.77 |
| | | 500 | 1.54 | 1.55 | 2.62 | 2.64 | 1.41 | 1.51 | 2.32 | 2.59 | 2.42 | 2.46 | 5.09 | 5.14 | 1.97 | 2.34 | 4.46 | 5.07 |
| | | 0 | - | - | 2.04 | 2.04 | - | - | 1.85 | 2.04 | - | - | 3.60 | 3.60 | - | - | 3.27 | 3.60 |
| | 25 | 100 | 1.25 | 1.27 | 2.04 | 2.09 | 0.99 | 1.15 | 1.87 | 2.04 | 1.66 | 1.70 | 3.64 | 3.74 | 0.95 | 1.32 | 3.30 | 3.60 |
| | | 200 | 1.29 | 1.30 | 2.06 | 2.10 | 1.13 | 1.25 | 1.89 | 2.04 | 1.76 | 1.79 | 3.69 | 3.77 | 1.20 | 1.66 | 3.33 | 3.60 |
| | | 500 | 1.35 | 1.36 | 2.12 | 2.13 | 1.29 | 1.34 | 1.97 | 2.09 | 1.95 | 1.97 | 3.82 | 3.84 | 1.67 | 1.89 | 3.52 | 3.80 |

(a) $S_q$ = 0.005 for $T$ = 5 deg C